

SIGNATURES IN LIGHTNING ACTIVITY DURING TENNESSEE VALLEY SEVERE STORMS OF 5-6 MAY 2003

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1. INTRODUCTION

During the first week of May 2003, the Tennessee Valley experienced 14 tornadoes. Those that moved across the Tennessee Valley Region of northern Alabama and southern Tennessee provided an opportunity for study using the North Alabama Lightning Mapping Array (LMA) (Goodman et al. 2004). On 5 May a classic supercell trekked across southern Tennessee spawning several tornadoes producing F0-F3 damage; on 6 May a high precipitation supercell moved across northern Alabama producing several F0-F1 tornadoes (Fig. 1). The life cycle of these supercells will be discussed by presenting their electrical and radar evolution.

2. LIGHTNING ACTIVITY IN THUNDERSTORMS

Numerous studies have shown that cloud flashes make up the majority of the flash activity within thunderstorms (Williams 2001; MacGorman 1993). Many results have shown an increase in ground flash activity during a decaying updraft. Lhermitte and Williams (1985) found that cloud flashes are most frequent during a strong updraft. According to the ice-ice charging mechanism theory (Saunders 1993), as the storm grows vertically through the mixed-phase region more charge is separated within the cloud leading to an increase in electrical activity and thus suggesting strong coupling between the electrical activity, microphysics, and kinematics within a thunderstorm.

A peak in the cloud flash activity prior to severe weather at the ground has been noted in several studies. Williams et al. (1999) observed a rapid increase followed by a sharp decrease in the cloud flash rate prior to severe weather onset in Florida thunderstorms; Williams et al. (1989) and Goodman et al. (1988) observed a similar flash trend in microburst producing storms in Florida and across North Alabama. This flash trend has been termed the lightning jump (Williams et al. 1999). Buechler et al. (2000) also observed a lightning jump at least 4 min prior to touchdown of an F1 tornado in Oklahoma. MacGorman et al. (1989) found that cloud flash activity was well correlated to the shear at 1.5 km in a tornadic Oklahoma supercell. For several tornadic storms that crossed North Alabama on 10-11 November 2002, results from a study

by Goodman et al. (2004) reveal that a downward increase in rotation occurred at the same time a lightning jump was observed. For severe thunderstorms in the Tennessee Valley, the total flash rate is typically around 100 flashes per minute.

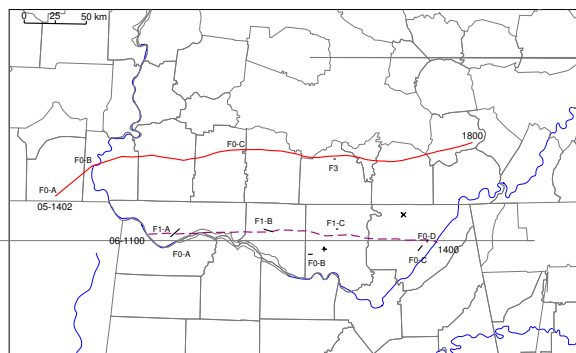


Figure 1. Map of the Tennessee Valley region of southern Tennessee and northern Alabama with storm tracks for the 5 (solid) and 6 (dashed) May 2003 storms. The times (UTC) indicate the ending and beginning times for the storm tracks. The tornado paths and magnitudes associated with each storm are also shown. The '+' marks the location of the LMA central processing site, and the 'X' denotes the location of KHTX.

3. METHODOLOGY

The North Alabama LMA is an array of 10 VHF sensors across the Tennessee Valley that detect radiation emitted by lightning (referred to as a source). Using GPS and wireless technology, the sensors locate the latitude, longitude, and altitude of the source and send that information back to a central processing site in Huntsville, AL (Fig. 1). Solutions can then be calculated and a flash algorithm applied to the processed data in an attempt to reconstruct the lightning channel. LMA source solutions were passed through the North Alabama LMA flash algorithm in order to reconstruct the flashes. This algorithm groups the VHF sources by their temporal and spatial variation from one another (B. McCaul, personal communication 2004). The algorithm performs numerous iterations until all the sources are either assigned to a flash or classified as noise. First each source is checked to see if it is within 0.3 sec of the previous source. If this condition is met a test is performed to determine if the sources are within a reasonable distance of one another. This distance is

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based upon the radial location of the source, a horizontal threshold depending upon the physics of lightning propagation, plus the radial location error of the LMA. Due to noise associated with source location error, sources occurring beyond 160 km of the network cannot be assigned to a flash. Assuming the time and space criteria are met, the source is assigned to a flash. Although the LMA is capable of detecting, but not discriminating between, cloud and ground flashes, data from the National Lightning Detection Network (NLDN; Cummins et al. 1998) was used to verify ground flash (CG) results. A 10 kA minimum threshold was placed on the positive ground flashes (+CG), identified by the NLDN, as suggested by Cummins et al., to remove the possibility of the NLDN detecting cloud flashes (IC hereafter, for brevity). The number of flashes were then determined for each interval of the radar volume scans (approx. 5 min), similar to the method performed by McCaul et al. (2002). This allows for a comparison to be made between the flash activity and radar parameters derived for each cell. The flash rate was calculated by dividing the total number of flashes occurring during each volume scan by the time interval of the volume scan and then converted to flashes per minute (fpm).

The radar data were collected with the WSR-88D located in Northeast Alabama (KHTX; Fig. 1). The reflectivity was gridded; and the maximum reflectivity, within 5 km horizontal of the storm centroid, was calculated at each vertical level. The Doppler velocity was dealiased and storm rotation was determined by analyzing the radial velocity along the radial for each elevation in the volume scan using the SOLO II software developed by NCAR. The height above MSL and range from the radar of the rotational couplets were also noted in order to calculate measures of horizontal rotation at each vertical level.

Storm data were obtained from the National Climatic Data Center (NCDC) storm events database. National Weather Service (NWS) tornado warnings were obtained from local NWS offices. Also, tornadoes will be referred to by their magnitude on the Fujita scale (Fujita 1981) and a letter, in alphabetical order, indicating the time of occurrence relative to other tornadoes of similar magnitude.

4. RESULTS

In this section the results from a radar and lightning analysis of a classic and a high precipitation supercell that occurred in the Tennessee Valley region of the southeastern United States on 5-6 May 2003 are presented. The results will investigate the trends in the electrical activity of the storms relative to tornadogenesis.

4.1 Classic supercell

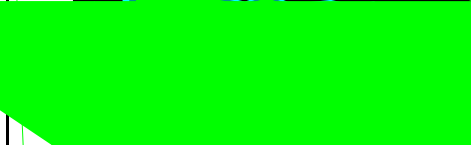
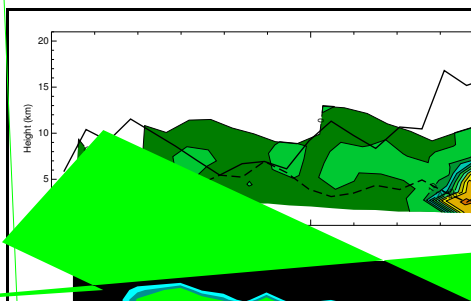
The classic supercell was fueled by the moist, warm sector air of a mature mid-latitude cyclone located in the East-Central Plains. The storm produced its first of 3 F0 tornadoes at 1405 UTC, but it was not until 1500 UTC that the storm was within approximately 150 km range from the radar to perform a radial velocity analysis. Figure 2a

shows the Doppler radar and lightning evolution of the storm between 1500-1655 UTC. One thing that stands out is the gradual downward increase of shear. The shear first begins increasing at mid-levels (5-10 km) to values above $5 \times 10^{-3} \text{ s}^{-1}$ at 1529 UTC. In the time leading up to the F0-C tornado (1548 UTC) the total flash rate first peaked at 56 fpm, 28 min prior to the tornado. Interestingly, the number of ICs declined nearly 250 flashes over the next 15 min, moments after the appearance of $5 \times 10^{-3} \text{ s}^{-1}$ shear values at mid-levels (Fig. 2a) and coincident with the reflectivity echoes above 10 km increasing to greater than 40 dBZ (Fig. 2b). However, the appearance of $5 \times 10^{-3} \text{ s}^{-1}$ shear at the lower radar beam elevation angles, prior to the F0-C, was accompanied by an increase in ICs. The CG rate and negative ground flashes (-CG) peaked at 34 fpm and 169 flashes, respectively, during the F0-C. The +CGs reached a peak of 13 flashes at 1554 UTC, minutes after the F0-C ended and concurrent with a local minimum in the echo heights (Fig. 2b). The production of ICs increased to nearly 200 flashes as the echo heights increased between 1554-1604 UTC and then both decreased simultaneously over the next 10 min.

The number of VHF sources gradually increased to a peak of over 86 000 sources at 1619 UTC (not shown), at which time shear again increased toward the ground. Figure 2a reveals the total flash rate increasing from 51 fpm at 1624 UTC to 82 fpm at 1629 UTC, 15-20 min prior to the touchdown of an F3 tornado, and coincident with shear values greater than $10 \times 10^{-3} \text{ s}^{-1}$ below 5 km. However, the CG rate at 1624 UTC was 24 fpm and decreased to 12 fpm at 1629 UTC during this increase of shear below 5 km, and coincident with a large decline in the echo tops; some echoes dropped nearly 6 km between 1624-1634 UTC (Fig. 2b). Between 1642-1649 UTC, shear greater than $10 \times 10^{-3} \text{ s}^{-1}$ appeared at all elevation angles as the total flash rate remained above 70 fpm after its peak at 1629 UTC. The +CG production was not very active in the 40 min prior to and during the F3, varying by less than 2 flashes from 1604-1649 UTC. By 1650 UTC, the storm became more disorganized as the 40 dBZ and greater echo heights continued to decrease below 5 km.

4.2 HP supercell

The high precipitation (HP) supercell that moved across northern Alabama on 6 May 2003 spawned several longer track tornadoes (Fig. 1) and caused flash flooding across the area. The HP supercell initiated near a warm front as it moved northward across northern Alabama. Due to the ambiguity of the radial velocity couplets associated with the tornadoes, a velocity analysis was problematic, and thus the shear profile could not be calculated for this storm. Figure 3 shows the total flash rate increased from 5-60 fpm as the heights of the 40-50 dBZ echoes grew 3.5 km vertically between 1100-1130 UTC. The F0-A and F1-A tornadoes occurred 3 and 5 min, respectively, after the total flash rate reached 60 fpm at 1130 UTC. During the time these two tornadoes were on the ground, the total flash rate remained around



and the subsequent increased IC production. These lightning jumps occurred prior to several of the tornadoes. During the 5 May storm, the increases in total flash rate were well correlated with the increases of shear at lower levels. The vertical stretching of vorticity by a strengthening updraft or downdraft, such as a rear flank downdraft, may have provided for these rapid increases in rotation.

Currently the authors are conducting more case studies on events in which tornadoes were not preceded by lightning jumps and storms for which lightning jumps were observed but tornadogenesis failed. The goal of this work in progress is to provide more insight on the lightning jump and its application to operational nowcasting.

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REFERENCES

- Buechler, D. E., K. T. Driscoll, S. J. Goodman, and H. J. Christian, 2000: Lightning activity within a tornadic thunderstorm observed by the Optical Transient Detector (OTD). *Geophys. Res. Lett.*, **27**, 2253–2256.
- Cummins, K. L., M. J. Murphy, E. A. Bardo, W. L. Hiscox, B. Pyle, and A. E. Pifer, 1998: A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network. *J. Geophys. Res.*, **103**, 9035–9044.
- Fujita, T. T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.*, **38**, 1511–1534.
- Goodman, S. J., D. E. Buechler, P. D. Wright, and W. D. Rust, 1988: Lightning and precipitation history of a microburst producing storm. *Geophys. Res. Lett.*, **15**, 1185–1188.
- Goodman, S. J., R. Blakeslee, H. Christian, W. Koshak, J. Bailey, J. Hall, E. McCaul, D. Buechler, C. Darden, J. Burks, T. Bradshaw, and P. Gatlin, 2004: The North Alabama Lightning Mapping Array: Recent severe storm observations and future prospects. *Atmos. Res.*, (in press).
- Lhermitte, R. M. and E. R. Williams, 1985: Thunderstorm electrification: A case study. *J. Geophys. Res.*, **90**, 6071–6078.
- MacGorman, D. R., D. W. Burgess, V. Mazur, W. D. Rust, W. L. Taylor, and B. C. Johnson, 1989: The relationship between lightning type and convective state of thunderclouds. *J. Geophys. Res.*, **94**, 13213–13220.
- MacGorman, D. R., 1993: Lightning in tornadic storms: A review. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards*, *Geophys. Monogr.*, Amer. Geophys. Union, No. 79, 173–182.
- McCaul, E. W., J. Bailey, S. J. Goodman, J. Hall, D. E. Buechler, and T. Bradshaw, 2002: Preliminary results from the North Alabama Lightning Mapping Array. *Preprints, 21 Conf. on Severe Local Storms*, Amer. Meteor. Soc., San Antonio, TX, CD-ROM, 11A.2.
- Saunders, C. P. R., 1993: A review of thunderstorm electrification processes. *J. Appl. Meteor.*, **30**, 642–655.
- Williams, E. R., M. E. Weber, and R. E. Orville, 1989: The relationship between lightning type and convective state of thunderclouds. *J. Geophys. Res.*, **94**, 13213–13220.
- Williams, E., B. Boldi, A. Matlin, M. Weber, S. Hodanish, D. Sharp, S. Goodman, R. Raghavan, and D. Buechler, 1999: The behavior of total lightning activity in severe Florida thunderstorms. *Atmos. Res.*, **51**, 245–265.
- Williams, E. R., 2001: The electrification of severe storms. *Severe Local Storms*, *Meteor. Monogr.*, Amer. Meteor. Soc., No. 50, 527–561.